World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:8, No:5, 2014

Integration of LCA and BIM for Sustainable Construction

Laura Álvarez Antón, Joaquín Díaz

Open Science Index, Civil and Environmental Engineering Vol:8, No:5, 2014 publications.waset.org/9998219.pdf

***Abstract*—**The construction industry is turning towards sustainability. It is a well-known fact that sustainability is based on a balance between environmental, social and economic aspects. In order to achieve sustainability efficiently, these three criteria should be taken into account in the initial project phases, since that is when a project can be influenced most effectively. Thus the aim must be to integrate important tools like BIM and LCA at an early stage in order to make full use of their potential. With the synergies resulting from the integration of BIM and LCA, a wider approach to sustainability becomes possible, covering the three pillars of sustainability.

***Keywords*—**Building Information Modeling (BIM), Construction Industry, Design Phase, Life Cycle Assessment (LCA), Sustainability.

I. Introduction

SUSTAINABILITY is based on three pillars (economic, social and environmental). The construction industry has a great impact in these areas. Firstly, construction processes have environmental impacts due to the resources consumed and the emissions generated. According to Directive 2010/31/EU (19 May, 2010), approx. 40% of the energy consumed in the European Union results from the construction sector. Moreover, it is a sector in expansion, and so energy consumption is increasing as well. The construction industry also consumes approx. 40% of natural resources and generates approx. 40% of total waste worldwide [1]. Secondly, it is an essential economic engine. In fact, it has been estimated that construction accounts for one tenth of the entire global economy [2]. Thirdly, buildings and infrastructures are essential for the well-being and life quality of the citizens due to the fact that they have a great influence on one's social interaction and health [3] and constitute a fundamental feature of the urban environment.

The construction industry as a whole is clearly moving towards sustainability, but some features play a more important role than others in this respect. One distinctive factor is that construction is a project-based industry. Each project is unique and has its own characteristics. These, in turn, are related to specific conditions, e.g. individual needs of the client, special locations [4]. Consequently, the design has to be flexible, so that performance can be improved simply by making a few changes [5]. Indeed, of all the different life-cycle phases that a project goes through, the design phase is the one with the greatest potential for influencing the project and adding value. Once the construction phase has been reached, the project has already lost most of its flexibility and only small alterations are possible, representing higher costs [6].

The construction industry is also characterized by having long-life products. The life span varies depending on specific features, such as location, technique, material and design [7]. Furthermore, the product may undergo various changes throughout the life cycle, which are difficult to predict. Therefore, there is a great deal more uncertainty concerning their future [5].

During its life cycle, every construction project involves a wide variety of stakeholders with different characteristics and interests. The construction process itself comprises companies of varying sizes, whereby small and medium-sized enterprises (SMEs) predominate [7].

Construction is regarded as an industry with low-level investment in research and development. This naturally hinders any form of improvement or evolution. SMEs constitute the highest percentage of the construction industry, while the larger firms are the ones with most resources for research and development [8]. The creation of temporary alliances for individual projects also hinders the application of new methods [9].

There are several features inherent in the construction sector which may lead to inefficiency and unsustainability. Firstly, the wide variety of stakeholders involved and the specific features of each project make any form of standardization difficult [5]. Secondly, there is often insufficient cooperation among the stakeholders themselves. This is mainly based on a lack of trust and open communication, which is characteristic for the whole industry. Thirdly, the process of tender is frequently based on price rather than generating value (or quality). This also hinders further development within the industry [10]. In fact, lack of cooperation and effective communication is one of the main causes of wasted resources. It has been estimated that the same information is entered up to seven times during one single building project [11]. In other words, only the time invested at the beginning of the project (30%) is really effective, whereas the rest of the time (60%) is used more or less inefficiently [12]. It is obvious that there has to be a shift away from such isolated efforts to a more collaborative environment.

II. How Can the Situation of the Construction Industry Be Changed?

It is clear that a change in the construction industry is needed in order to improve performance and achieve a more sustainable approach. Since sustainability is based on three

Laura Álvarez Antón and Joaquín Díaz are with the Technische Hochschule Mittelhessen, Giessen, Wiesenstrasse 14, 35390 Germany (e-mail: laura.alvarez.anton@bau.thm.de, diaz@bau.thm.de).

pillars (environment, social and economic), a holistic approach is required so as to reach an acceptable balance.

In order to accomplish such a change, the main areas for improvement have to be highlighted. This paper will analyze three main fields as an approach to sustainable construction.

Firstly, more effort should be devoted to the early design phases. These phases have the greatest potential in terms of influencing the project. The cost of implementing changes increases as the project evolves, due to a reduction in flexibility. A major part of the expenses are incurred during the construction phase, but, as mentioned above, the project has already lost flexibility by this time and any alterations result in higher costs [6]. Therefore, an exhaustive analysis of the design has to be carried out in the early phases to improve performance and avoid wastage.

Secondly, one of the main aims of the construction industry is to profit from all available knowledge and technology with a view to achieving sustainable construction [13]. BIM and LCA are ideal for this purpose. The working environment has to be supported by a more collaborative framework. BIM can contribute to improving communication and collaboration among the different stakeholders involved in the project.

Thirdly, in order to improve environmental performance, the respective criteria should be considered in the early project phases. In this connection, life-cycle assessment (LCA) is one of the most widely used tools for evaluating environmental performance.

The three key areas mentioned above will now be analyzed in detail with the aim of determining their potential for improving overall performance in the construction industry.

A. Sustainable Design (Integrated Design)

As a starting point, the project phases with the highest capacity to influence a project should be considered. Clearly, the early design phases fall into this category while, at the same time, adding extra value. Once the project has reached the construction phase, it has already lost flexibility and implementing changes becomes harder and more expensive [6]. On the other hand, decisions taken in the early design phases may help to prevent possible errors and overruns. Similarly, it is essential to define all the project needs in the early planning phases to avoid future design changes [14]. Consequently, design can be viewed as the first step towards achieving sustainability, as has been determined by the British government: “Good design is synonymous with sustainable construction” [15].

Sustainable design should be exhaustive, with greater efforts made during the early phases, but considering the life cycle of the building as a whole. Sustainable construction is not to be seen as a complicated or expensive trend; it is a question of implementing integrated design, where all components of a project are included within a holistic framework rather than being analyzed individually. The design phase is the key factor in this respect. It is here that one must try to reduce the consumption of resources and energy, create a comfortable inside atmosphere, restrict pollution and sink costs [16].

Coordination between the different stakeholders is also essential [14]. They must all move in the same direction to achieve a balance between the three pillars of sustainability [16].

Environmental criteria also have to be considered from the very beginning. This supports decision-making, thus helping to achieve sustainable design. Stakeholders should be constantly aware of the environmental performance of the project and appreciate the need to include such criteria at all times.

In order to face the new challenges in the construction field, innovative technologies have to be implemented [17]. The integration of existing methods such as BIM and LCA is important for supporting sustainable design.

B. Building Information Modeling (BIM)

A profitable synergy is developing between BIM and sustainable construction. Sustainability depends on integrated design with an overview of the complete project, and due to its particular characteristics, BIM facilitates such a process [18]. BIM systems have the means to improve a project’s information flow, achieving better performance and quality. BIM enhances transparency and supports collaborative work among the stakeholders beginning in the early project phases. All this helps to reduce wastage and avoid future errors [15]. BIM models provide structured data. Therefore they can be used for industrializing the construction process, for example in prefabrication. They also lead to a reduction in costs, time, and wasted resources, thus increasing sustainability. In addition, BIM-based tools support various analyses and simulations, the results of which form a basis for decision-making and ultimately improve the performance of the building [18].

Due to its specific features, BIM has positive impacts on the three pillars of sustainability. Firstly, with regard to economic aspects, it has the capacity to reduce design costs by improving information management and enhancing coordination, with the result that fewer resources are wasted. Secondly, with regard to social aspects, BIM-based tools facilitate the analysis and simulation of different parameters, which with traditional tools would be very complicated and require manual data entry. Complex analyses (e.g. daylight) can be performed to create better working and living conditions, thus adding to comfort and well-being. Thirdly, with regard to environmental aspects, BIM supports a number of different analyses [19]. However, its capacity for improving environmental performance would be enhanced through integration with other special tools, such as LCA.

C. Life Cycle Assessment (LCA)

Life-cycle assessment (LCA) can be regarded as one of the most suitable methodologies for assessing environmental impacts [20]. It is currently being fostered as the method of choice in improving the environmental performance of a building as a whole [21].

LCA helps stakeholders to comprehend the various environmental impacts of the respective project during its

Open Science Index, Civil and Environmental Engineering Vol:8, No:5, 2014 publications.waset.org/9998219.pdf

Open Science Index, Civil and Environmental Engineering Vol:8, No:5, 2014 publications.waset.org/9998219.pdf

different life-cycle phases [21]. It also increases social awareness of such impacts. As a rule, the costs of environmental impacts are not included in the final budget. Therefore the possibility of showing the environmental costs and effects of a specific construction project contributes to sustainability. In our present-day society, it is important to be conscious of the real costs resulting from environmental impacts [22].

LCA supports decisions taken during the design phase by providing a scientific basis for environmental criteria [21]. It guides the selection of materials, the planning of procedures for residues management, the development of the construction plan, etc. [23]. It also creates the possibility of analyzing the specific impacts of different alternatives, so that the most suitable one can be selected [5].

Since LCA covers the entire project life cycle, it can be used to highlight the main opportunities for improving environmental performance at all stages of construction [23].

Despite the noticeable advantages that LCA has for the construction project, it also has some inherent limitations that could be improved if it is integrated with other tools. Some of these limitations are described below.

One of the main limitations of LCA is data availability. The quality of the results depends on the quality of the data, but comprehensive data are not always available or they are not updated, therefore assumptions sometimes have to be made, which increases the inaccuracy of the assessment [21]. Furthermore, working with LCA usually requires the assistance of an expert due to the complexity of the process and the results.

There is also a lack of standardization concerning its application. ISO standards only contain recommendations [24]. LCA methodology fits better to industrialized processes than to construction procedures, where it is hindered by a number of special features and the long life span. In addition, construction products are made up of a wide variety of different elements, each with their own characteristics. All these factors make it difficult to evaluate the construction project during its life cycle.

Furthermore, there is a general lack of information in the early project phases. As a result, LCA evaluations are usually developed in the late project phases (i.e. after construction or during the use phase). Although more information is available in the later phases, the results of the assessment are not as useful as they are in the early phases [25]. Finally, the project information required for the assessment has to be entered manually, which makes it a time-consuming task and might lead to errors [9].

LCA application in the construction industry would be improved through integration with other methods, such as BIM. In this way, synergies could be created with the chance of including environmental criteria in the decision-making process during the early project phases.

III. Integration of LCA and BIM in the Early Design Phases

Sustainable construction aims for the lowest environmental impact, while encouraging social and economic development. A sustainable design tool has to be able to evaluate building performance according to different criteria. At the same time, the information must be integrated in the design framework in order to compare different alternatives [26]. For this purpose, a huge amount of information has to be handled. This is one of the reasons why some tools are implemented in the late project phases when solutions have already been developed.

This problem could be solved by integrating different tools and using them for assessing decision-making in the early design phases. With the integration of LCA and BIM, a wider approach to sustainability would be achieved and the efficiency of both tools would be improved.

A. SWOT Analysis of the Integration

This section of the paper includes a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis with regard to the integration of LCA and BIM in the context of achieving an efficient decision-making tool for the early project phases. The internal assessment will show the strengths and weaknesses and the external assessment will show the opportunities and threats.

1. Internal Assessment (Strengths and Weaknesses)

Strengths

By integrating BIM and LCA, a new tool can be created with synergies comprising a large number of positive features:

- Higher capacity for accommodating the three pillars of sustainability
- More extended use of environmental criteria by various stakeholders
- Increased efficiency with regard to environmental assessment, making this task easier and less time-consuming
- Avoidance of manual data re-entry: once the construction information is in the BIM model, there is no need to re-enter it for LCA, and the designer has easy access to this information for decision-making
- More information available about the project during early phases, leading to greater benefits in general
- Higher effectiveness of environmental assessment (e.g. with regard to decision-making) due to its being performed in early design phases
- Possibility to compare predicted environmental performance with real performance and chance to learn from experience

Weaknesses

The integration of BIM and LCA also has some less positive features which need improving through further development:

- Different stakeholders involved in the construction industry must be trained to include environmental criteria in their assessments
- LCA process and way of presenting data are not standardized
- Lack of environmental data for carrying out LCA

Open Science Index, Civil and Environmental Engineering Vol:8, No:5, 2014 publications.waset.org/9998219.pdf

- Assumptions have to be made for LCA calculation, thus increasing uncertainty of the assessment
- Further development needed concerning interoperability between BIM and LCA software

2. External Assessment (Opportunities and Threats)

Opportunities

The integration of BIM and LCA would benefit from the positive features of the immediate environment to enhance its potential:

- It is becoming compulsory in the construction sector to consider environmental criteria. Various initiatives are being launched by the different governments and the European Union for this purpose.
- There is increased demand for sustainable constructions in the market.
- These tools already exist. It is just a matter of integrating them to generate synergies.
- There is a real need of a tool with such features in the market.
- There is a direct need to change the way of working in the construction industry, and such an integrated tool and its application in the early design phases could contribute to this change.
- BIM is already becoming more widely accepted in the construction industry. If LCA is integrated in the BIM framework, this will make it even more acceptable for the stakeholders. The advantages derived from BIM implementation would act as a trigger for LCA performance during the early project phases.

Threats

The integration of BIM and LCA will also have to face some threats from the immediate environment and overcome them:

- Sometimes construction industry stakeholders are not aware of the importance of considering environmental aspects among project criteria at an early stage.
- Some stakeholders may refuse to implement this step due to the effort required for integrating the tool in the early design phases.
- There is a lack of research and development in the construction industry.
- There is a wide variety of stakeholders with different characteristics involved in the construction industry. This hinders standardization in the industry and makes it more difficult to implement change.
- There is a lack of interoperability between the different software systems.

After evaluating the strengths, weaknesses, opportunities and threats, it could be concluded that implementation of LCA and BIM needs further development.

The main drawbacks are: (1) lack of research and development, and (2) reluctance of some stakeholders to change their way of working. On the other hand, there are significant advantages resulting from the integration of powerful tools like BIM and LCA in terms of synergies created and chance of early implementation. This greatly increases the potential for sustainable construction.

B. *Suggested Integrations*

The first approach is based on extracting direct project data from the BIM model and using it to perform an LCA of the complete construction during its entire life cycle. The BIM model is used as the main source of information and thus manual data re-entry is avoided. A real-time assessment can be made and the results considered during the decision-making process. In this way, environmental criteria are integrated in the early design phases. Different alternatives can be compared from an environmental point of view and the most suitable one selected. Moreover, it becomes possible to assess single elements and thus improve the selection process with regard to materials and elements during the design phase.

The second approach is based on including LCA-related information pertaining to different construction elements in the properties of the various BIM objects. In this way, when the designer wishes to select an element from the various BIM objects included in the libraries during the design phase, he or she can check the respective environmental features. This means that environmental information is considered on the same level as the rest of the features during the decision-making process. In other words, this approach may be seen as a first step towards the inclusion of environmental criteria in the pre-design and design phases. Moreover, a rough and mainly material-oriented estimation of the building's LCA can be made based on a list of the features of the different elements included in the model [27], [28].

IV. Conclusion

A sustainable design tool has to be able to evaluate the building's performance according to various criteria (environmental, social and economic) at the same time as the information is integrated in the design framework so that different alternatives can be compared. For this purpose, a huge amount of information has to be handled. The integration of LCA and BIM allows a more extensive approach to sustainability with significant strengths and opportunities, as mentioned above.

Of the two types of approach described in the text, the first one is clearly more comprehensive and allows evaluation of the complete construction during its entire life cycle. The second one, which is based on the having LCA-related information included in the features of the various BIM objects, is more suitable for selecting materials and elements. It is mainly material-oriented and could be seen as a starting point for the incorporation of environmental criteria in the early design phases.

References

[1] ISO, "ISO standard set to reduce environmental impact of buildings". 2010 [Online] Available at: http://www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1344 [Accessed 28 May 2013].

[2] Adapt4EE Consortium,."Adapt4EE. 7th Framework Programme, 2012 [Online] Available at: http://www.adapt4ee.eu/adapt4ee/project/motivation.html [Accessed 28 May 2013].

[3] Novem, "Sustainable housing policies in Europe", *3rd European Ministers Conference on sustainable housing*, Belgium, 2002.

[4] O. Nawari, "BIM Standard in Off-Site Construction," *Journal of Architectural Engineering*, vol. 18(2), June 2012, pp. 107 – 113.

[5] M. M. Khasreen, P. F. Banfill and G. F. Menzies, "Life-Cycle Assessment and the Environmental Impact of Buildings: A Review." *Sustainability*, vol. 1(3), Jan. 2009, pp. 674 – 701.

[6] R. Burke, "Project Management. Planning and Control Techniques", 3rd ed., John Wiley & Sons LTD, Chichester, 2001, pp. 26 – 31.

[7] Organization for Economic Co-operation and Development, "Design of sustainable building policies: scope for improvement and barriers," *Working Party on National Environmental Policy*, Jun. 2002.

[8] European Foundation, "Trends and drivers of change in the European construction sector: Mapping report," *European Foundation for the Improvement of Living and Working Conditions*, Dublin, 2005.

[9] C. Eastman, P. Teicholz, R. Sacks, and K. Liston, "BIM Handbook. A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors," 2nd ed., New Jersey: John Wiley & Sons, Inc., 2011.

[10] S. O. Cheung, S. P. Wong, and H.C. Suen, "Behavioral aspects in construction partnering," *International Journal of Project Management* , vol. 21, pp. 333-343, 2003.

[11] J. Sjøgren, buildingSMART Norge, 2011. [Online] Available at: http://www.buildingsmart.no/article87.html [Accessed 20 June 2013].

[12] WSP and Kairos Future, WSP, 2011. [Online] Available at: http://www.wspgroup.com/en/wsp-group-bim/10-truth-bim/ [Accessed 18 May 2013].

[13] W. Chong, S. Kumar, C. Haas, S. Beheiry, L. Coplen, and M. Oey, "Understanding and Interpreting Baseline Perceptions of Sustainability in Construction among Civil Engineers in the United States," *Journal of management in engineering*, vol. 25 (3), July 2009, pp. 143-154.

[14] Bundesministerium fu r Verkehr, Bau und Stadtentwicklung, "Mo gliche Ursachen fu r Kosten-und Terminu berschreitungen bei der Realisierung von Großprojekten," *Sitzung Reformkommission Bau von Großprojekten am 17.04.2013*, Berlin, April 2013. [Online] Available at: http://www.bmvi.de//SharedDocs/DE/Artikel/UI/reformkommission-bau-von-grossprojekten.html?nn=38976 [Accessed 19 June 2013].

[15] HM Government, "Industrial strategy: government and industry in partnership. Building Information Modelling", 2012.

[16] C-SanD, "Sustainable Development and Sustainable Construction", Loughboroung University, 2001.

[17] Taskforce on sustainable construction, "Accelerating the Development of the Sustainable Construction Market in Europe," *Report of the taskforce on sustainable construction composed in preparation of the communication "A lead market initiative for Europe*, 2007.

[18] McGraw-Hill Construction, "The Business Value of BIM in Europe. Getting Building Information Modeling to the Bottom Line in the United Kingdom, France and Germany," *SmartMarket Report*, Bedford: McGraw-Hill Construction, 2010.

[19] Autodesk, 2005. "Building Information Modeling for Sustainable Design," Autodesk, Inc., 2005. [Online] Available at: http://images.autodesk.com/adsk/files/bim_for_sustainable_design_jun05.pdf [Accessed 14 May 2013].

[20] European Commission, European Platform on Life Cycle Assessment (LCA), 2012. [Online] Available at: http://ec.europa.eu/environment/ipp/lca.htm [Accessed 13 July 2013].

[21] Georgia Institute of Technology, "AIA Guide to Building Life Cycle Assessment in Practice," Washington DC: American Institute of Architects, 2010. [Online] Available at: http://www.aia.org/practicing/akr/AIAB089185 [Accessed 22 April 2013].

[22] M. Buyle, J. Braet, and A. Audenaert, "LCA in the construction industry: a review," *Renewable and Sustainable Energy Reviews*, vol. 26, Oct. 2013, pp. 379 – 388.

[23] ENSLIC, "Energy Saving through Promotion of Life Cycle Assessment in Buildings", *Intelligent Energy Europe*, European Commission, 2007 [Online] Available at: http://circe.cps.unizar.es/enslic/texto/proj.html [Accessed 5 July 2013].

[24] ISO 14040:2006, "Environmental management- Life cycle assessment- Principles and framework". [Online] Available at: http://www.iso.org/iso/catalogue_detail.htm?csnumber=37456 [Accessed 24 June 2013].

[25] W. Tritthart, H. Staller, I. Zabalza, T. Malmqvist, B. Peuportier, C. Wetzel, M. Hajpal, E. Stoykova, G. Krigsvoll, " LoRe-LCA State of the art report - Use of Life cycle assessment Methods and tools," Low Resource consumption buildings and constructions by use of LCA in design and decision making, Deliverable D2.1 a+b, FP7-ENV-2007-1-LoRe-LCA-212531, Dec. 2010.

[26] T. Hakkinen and A. Kiviniemi, "Sustainable Building and BIM. Melbourne," World Sustainable Building Conference SB08, Melbourne, Sept. 2008, CSIRO Commonwealth Scientific and Industrial Research Organization.

[27] J. Díaz and L. Álvarez Antón, "Sustainable construction approach through integration of LCA and BIM tools," ICCCBE 2014 Conference, submitted for publication.

[28] L. Álvarez Antón and J. Díaz, "Integration of Life Cycle Assessment in a BIM environment," Creative Construction Conference 2014, submitted for publication.

Open Science Index, Civil and Environmental Engineering Vol:8, No:5, 2014 publications.waset.org/9998219.pdf